Ph.D Synopsis

"Connection between Disk and Coronal Emission from AGN"

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1 INTRODUCTION:

A black hole has very strong gravitational field which do not allow even light to escape from its influence. The surface of a black hole is a boundary of the Universe which, separates it from an interior region that is observationally unknowable-causally disconnected from us (Eardley et al 1975). One of such a strange and compact object's (M87) image has been released on Wednesday, 10 April, 2019 by Event Horizon Telescope (EHT). What make possible to take image of such black hole? Absolutely the edge on technology which made possible but itself the back hole environment shining in the image due to the falling matter (i.e the accretion of matter) from surrounding on the super massive black hole at the center of supermassive elliptical galaxy M87. The exotic phenomena that are occurring at the center of the Active galactic nuclei (AGN) makes the study of such objects possible.

In year 1609, Galileo Galilei, introduced modern way to study astronomy by introducing telescope which is far better than natural detector eye. The advancement in detector from photographic plates to today's CCDs have played major role in the evolution of the field of astronomy. Observations by using this tools found that there are billions of groups of stars with each group contains billions of stars bound gravitationally this groups of stars individually known as galaxies. This galaxies are different in sizes and shapes, distributed in the universe irregularly and in-homogeneously forming a groups, in which our own Milky way also present.

In 1926, Edwin Hubble classified galaxies according to their morphological structures in tunning fork diagram. Generally the spectrum of galaxies is the integrated black body radiation (BBR) spectrum of the stars along with few absorption lines due to the stars and ISM within it. In early 20^{th} century, researcher have found strong nuclear emission lines in the spectra of few of the nebulae. In 1943, Carl Seyfert also evidenced similar features in group of some selected galaxies. These low-luminosity galaxies were then regarded as the Seyfert galaxies, which posses an active nucleus with detectable host galaxy. When viewed through large telescopes these galaxies appeared as spiral galaxies but spectroscopically they exhibited strong and high-ionization emission lines. The Seyfert galaxies were divided in to two classes according to the broad base of the emission lines and featureless continuum that supresses the absorption lines from the host. Seyfert 1 galaxies posses both

broad lines (width $\sim 10^4$ km/s) and narrow lines (width $\sim$ 100 km/s), where the width of the emission lines weaker through the sub-classes (i.e. Seyfert 1.5, 1.8 & 1.9) and becomes very narrow in the Seyfert 2 galaxies.

This trend of decreasing width of the broad lines leads to the unification of Seyfert galaxies. There are few AGN that are very luminous than normal galaxies, and appeared like a star, as a result are named as quasi-stellar objects or Quasars. The quasars are very compact and spatially unresolved objects and differ from Seyferts due to negligible stellar absorption and weak narrow lines relative to the broad lines.

After the second world war when the radio telescopes were pointed towards the sky a large number of radio emitting sources were detected. Most of the radio emitting sources were later found to be of elliptical galaxies, known as radio galaxies. The radio galaxies were identified into two classes, the broad line radio galaxies (BLRGs) and the narrow-line radio galaxies (NLRGs). BLRGs are variable elliptical galaxies with broad and narrow emission line spectra emitting most of their energy in the radio band, while NLRGs are the radio loud galaxies, however, do not exhibit variability. There is another class of AGN that exhibit very-low nuclear-luminosity and as known as Low-ionization nuclear emission-line region galaxies(LINERs) (Heckman 1980). These galaxies are similar to Seyfert 2, spectroscopically strong low -ionization lines like [OI] λ 6300 and $\lambda\,\lambda$ 6548, 6583. Nearly half of the LINERs are present in nearly half of spiral type and exhibit emission lines at detectable levels (Ho, Filippenko and Sargent 1994). LINERS are distinguished from Seyferts and Quasars on the basis of the different flux ratios, but still the connection between these two types is not clearly understood. Few of the AGN show short time-scale variability ($\sim$ a day) in flux and exhibit high polarization. These radio loud sources were later identified as optically violent variables or OVVs, which have few common properties with BL Lac objects. Both these objects show beaming effect and are collectively known as blazars.

Although there are several classification made on the basis of multi-wavelength observations, they all are unified together under single model known as Unified Model of Active Galactic Nuclei. This model assumes the difference in the observational differences due to different orientation effects.

2 Abstract of proposed work:

In the proposed work we plan to study correlations in multi-wavelength observations of AGN. The study of AGN variability is important to understand the central nuclei. This is because the AGN are not resolvable even with the present or planned optical telescopes. The past studies on short time scales, the changes in observed features of spectral lines and the correlations and delays between variations in different continuum or line components have given a crucial information like the nature and position of these emission components. The previous studies centered on the AGN variability have delineated severeal radio-quiet AGN and blazars.The proposed study is aimed to find the correlation between the X-ray and UV/Optical variability of AGN. This utilizes the best available techniques and tools to probe central part of the universe's most powerful engine, which is not yet fully understood.

3 Review of Literature and Development in the subject:

Now it is well established that center of all galaxies host a super massive black hole. As black holes do not radiate electromagnetic or gravitational waves, therefore their direct study is not possible so they can only be studied due to gravitational influence on neighboring material (Zeldovich and Novikov, 1971). However,

their investigation is possible only through the study of accreting matter from surrounding, which spirals around the SMBH making a disk. Such black holes are known as Active Nuclei and their host as the AGN. The accreted mass is redistributed in accretion disks as a consequence of angular momentum transfer (Papaloizou, 1995). This disk be very thin i.e. must have very small height relative to its radius (R), effective cooled and keplarian. The luminosity of the AGN is mostly dependent on the mass accretion rate and is governed by the equation, $L_{acc} = \eta \dot{M} c^2$ where η is the efficiency of accretion and $\dot{M}$ is the mass accretion rate. Through, there are several classes of AGN but they all are powered by the same accretion mechanism. As a result this accretion property leads to the unification of AGN. Most successful model of AGN unification was proposed by Autonnuci (1993) which was later modified by Urry & Padovani (1995). The modification was mainly based on two factors. i.e., orientation and covering factor (i.e. torus) of spanned disc around SMBH (Elitzur, 2012). The effective temperature profile of a steady thin disc goes as $T(R) \propto R^{-3/4}$ (Shakura 1973), according to which an average SMBH have temperature $\sim 10^5 K$ emits continuum radiation in UV/optical region. Observed spectra of such AGN exhibit two types of emission lines one as narrow lines with width $\sim$ 100 km/s another broad lines with width more than 2000 km/s. The broad lines are originated from the cool dense clouds that are rotating faster near the nuclei, while the narrow lines originated from the cold but more distant clouds which are rotating relatively slow. The Doppler effects due to the fast rotation of clouds provides necessary broadening and these regions are known as the broad line regions (BLRs) and narrow line regions (NLRs) respectively (Antonucci 1993).

The X-ray observations of such a sources have a history of their study from balloons to space based telescopes. The space telescopes like XMM-Newton, Chandra, ASTROSAT etc have a very good detectors capable to provide the spatial as well as temporal information of incoming photons. The X-ray observation showed that AGN are X-ray dominant sources. To explain the origin of the X-ray emission from AGN, scientist have proposed a region of highly relativistic and energetic particles near the central nucleus called as 'corona'. The UV/optical seed photons from disc enters into the corona, where they undergo Inverse-Compton scattering, where energy of the reprocessed photons is enhanced upto keV (i.e. X-ray photons). This non-thermal mechanisms produces power law spectrum X-ray emission. The reflection of these X-ray photons back to the disk and their interaction with the neutral atoms produces Fe lines and the observed Compton hump. AGN often show variability in continuum as well as broad emission lines at all the observed wavelengths. Optical continuum variability was observed even before the emission-line redshifts were understood (Matthews and Sandage 1963). The time delays between the direct coronal emission and the reflected emission were later identified as reverberation time lags. The studies have shown that the emission line variability follows the continuum variations in almost all sources. The study of variability of AGN add another window to look inside the compact central nuclei, which otherwise are invisible.

4 Scientific objectives of study:

- High qaulity data from continuous observations employing space telescopes such as ASTROSAT, XMM-Newton, Chandra, Suzaku, Swift and NuSTAR can be utilized to find out the correlation between the optical/UV and X-ray emission from AGN.
- To find the mechanism that is responsible for variability in different bands of wavelength.

- Another objective of the proposed study is to investigate the connection between emitting regions and to investigate whether they support the unification model or not.
- The study also aims to find the possible time lags between the UV/optical and X-ray variabilities, which in turn will reveal the mechanism and morphological structure of the AGN.

5 Methodology:

Investigation of the above mentioned scientific objectives which strengthens the understanding of the subject. While doing PhD we will participate in the national and international workshops, conferences and schools where we will discuss and learn about our subjects from experts. The investigation requires a large and continuous multi-wavelength data from space telescopes such as XMM-Newton (X-ray multi mirror mission) which provides a high time-resolution observations and high resolution spectroscopy, The Suzaku telescope is X-ray observatory having a moderate spatial resolution but high spectral resolution, the Swift telescope is multi-wavelength observatory important for spectral energy distribution also Chandra, and newly launched Indian space mission ASTROSAT. The data from respective archives will be taken from the HEASARC platform also we will like to submit our own proposal for fresh data from ASTROSAT.

The data will be acquired according to our requirements, which then will be processed following the documentation of respective observatory, like Chandra data analysis follows CIAO threads that provide detailed information on each step. The space mission data will be in raw form that contains event files as well as spacecraft information files. The collected data contains both level 1 (aspect solution and bad pixel files will be applied to raw data) and level 2 (level1 files will be filtered for good time intervals) data files. These event files in the raw data need to be calibrated using calibration databases (CALDB) provided by the calibration team of the respective space mission. The generation of calibrated event files for sources and instruments following routines provided by the corresponding telescopes will be used to extract science data from them. The chandra repro script covers the threads such as identifying bad pixels, applying aspect solution and filtering it for the good time intervals. After that flaring will be removed and background subtracted from it and finally the event files will be ready for the use of science study. The lightcurve will be obtained using dmextract tool. Spectral analysis can be done using the *XSPEC* and *SHERPA* tools. The data from other observatories will also be processed following similar tools available for respective missions. The XMM-Newton data processing will be performed using *epchain pipeline* process which removes bad pixels from the event files, gain calibrations and finally produces good time event files the data analysis/reduction will be carried using the XMM-Newton Scientific Analysis System (*SAS*) and the process includes calibration of raw event data sets, screening of calibrated data, extraction of images and spectra, also source detection and scientific analysis of calibrated products. Then the processed event files will be analyzed according to science objectives. Also for SWIFT there is XRT data reduction process from which we will derive the images, lightcurves and spectra using SWIFT-XRT products. Tools *xrtpipeline* will be used to generate calibrated event files as well as lightcurves. SUZAKU pipelne provides *sxt pipeline* for ASTROSAT. The light curves and spectra will be plotted using software tools like epchain for XMM-newton, *XSELECT* for Swift and Suzaku and *XSPEC* for ASTROSAT.

The resultant extracted products will be imported to the *XSPEC* , where model fitting will be done for individual source and the results will be compared with theoretical models at the end. The variability and time

lags between different bands will be studied by comparing the plotted lightcurves. The lightcurves provide the potential way to understand the variability of sources, where we plot the intensity as a function of time. The light curves yield information regarding the processes that are operative near the sources. All these processes can be investigated under the time resolved spectroscopy (anything that allows us to measure the temporal dynamics & the kinematics of photophysical process). There are various other methods and statistical techniques already in use, those will be used in the present study also. All the data analysis process will be done using the computational facilities available in the School of Physical Sciences of Swami Ramanand Teerth Marathwada University, Nanded. All the necessary software and tools with fully updated technical facility are available in the school.

6 Importance of Study:

AGN exhibit very high luminosity and can be observed at very large distances. These properties make them suitable targetes as the distance measuring tool, as a result they are placed at the top of distance ladder in astronomy. By using time machines (i.e.telescopes) we can see the earlier stages of universe or evolution of the universe by tracing AGN located at higher redshifts. This is because the AGN in early epochs of the universe might have now faded to very low luminosities. The nuclei of AGN are very extreme, compact and unresolvable therefore, they are universe's biggest uncontrollable experimental laboratories, where we can varify the proposed models further, their stretches the limits of the present theories and knowledge about universe and mathematical models developed over centuries. The AGN are neither completely understood nor any of the existing models explains their physics completely. As a result it invites more advanced theories that will expand our understanding frame of reference.

7 National and International status:

The field of AGN research is still evolving and has became the topic of frontline research at global level. AGN are the hot topics in the field of Astronomy and Astrophysics. The X-ray and optical variability of AGN is studied at international level. There are several groups that are working in the field and are led by Prof. C. Martin Garkell from University of California at Santa Cruz, Dr. I. M. McHardy from University of Southampton, Southampton, Dr. Bradley Peterson from Ohio state University, Prof. Andrew C. Fabian from University of cambridge, UK and many more from southampton etc. At national level, Dr. Gulab Devangan and Dr. Ranjeev Mishra from IUCAA, Pune and their research groups are working on the topic related to timing analysis and variability of X-ray emission from AGN sources.

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